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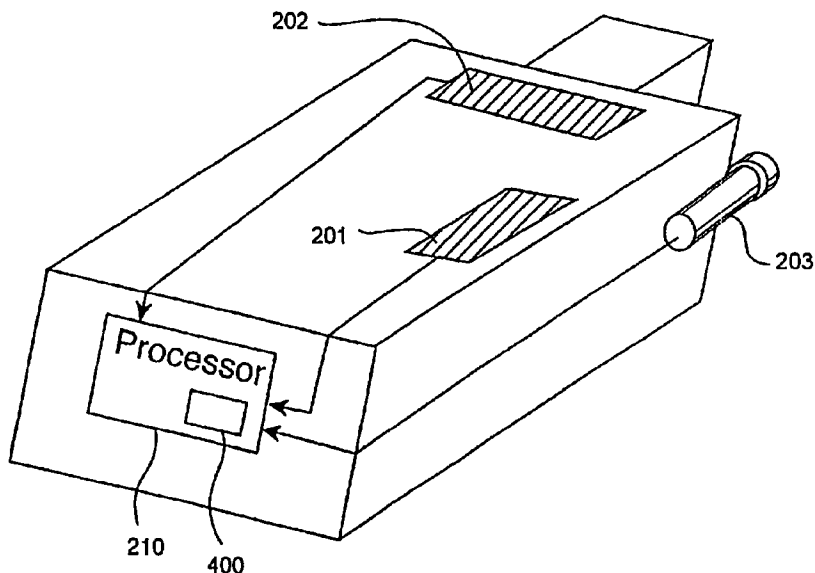
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(54) Title: METHOD AND SYSTEM FOR CORRECTING KEYSTONING IN A PROJECTOR ARBITRARILY ORIENTED WITH RESPECT TO A DISPLAY SURFACE



(57) Abstract: A method corrects keystoneing in a projector arbitrarily oriented with respect to a display surface. An elevation angle, a roll angle, and an azimuth angle of an optical axis of the projector are measured with respect to the display surface. A planar projective transformation matrix is determined from the elevation, roll, and azimuth angles. A source image to be projected by the projector is warped according to the planar projective transformation, and then projected onto the display surface.

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## DESCRIPTION

METHOD AND SYSTEM FOR CORRECTING KEYSTONING IN A PROJECTOR  
ARBITRARILY ORIENTED WITH RESPECT TO A DISPLAY SURFACE

## Technical Field

This invention relates generally to image projectors, and more particularly, to correcting keystone problems in projected images.

## Background Art

Portable digital image projectors are common. These projectors, while connected to a PC or VCR, sit on a table and are aimed at a projection surface to show a "slide" presentation or a video. Many of these projectors use transmission LCDs, and typically only have a single main lens. The projectors can display images one at the time or as a sequence of images.

These projectors are typically designed so that level undistorted images are projected on the projection surface when the projector is placed horizontally on a level support surface, so that the projector's optical axis is lined up perpendicular to the, typically, vertical projection surface. If any of the above assumptions is violated, then the resulting image on the projection surface may not be rectangular and will be, at best, a trapezoid, and at worst an arbitrary quadrilateral. This

problem is called keystoneing.

With prior art projectors, the only way to correct keystoneing is to tediously adjust the physical position of the projector by moving it around, tilting and rotating it, until a near rectangular image is displayed. In some cases, it may be impossible to physically adjust the position of the projector. For example, the projector may need to be well above or below the display surface. Some prior art projectors correct the distorted image optically or by the user providing projector positional data.

U.S. Patent No. 5,548,357, "Keystoneing and focus correction for an overhead projector," issued to Appel et. al. on Aug. 18 1998, describes a system where a test slide is displayed. A user identifies line pairs most parallel to each other. The line pair identification activates a distortion correction program that uses the oblique angle between the horizontal plane through the projector and the viewing screen.

U.S. Patent No. 5,795,046, "Method for pre-compensating an asymmetrical picture in a projection system for displaying a picture," issued to Woo on Aug. 1998, describes a system where the projection angle, and the trapezoidal error, is compensated for by the user entering in positional information into the system via a keyboard.

### Disclosure of Invention

A method corrects keystone in a projector arbitrarily oriented with respect to a display surface. An elevation angle, a roll angle, and an azimuth angle of an optical axis of the projector are measured with respect to the display surface.

A planar projective transformation matrix is determined from the elevation, roll, and azimuth angles. A source image to be projected by the projector is warped according to the planar projective transformation, and then projected onto the display surface.

### Brief Description of Drawings

Figure 1a is an illustration of a projector oriented perpendicularly to a planar display surface;

Figure 1b is an illustration of a projector oriented obliquely to the planar display surface;

Figure 2 is an illustration of a projector according to the invention;

Figures 3a-c illustrate three rotational angles associated with projectors;

Figure 4 is a flow diagram of a warping function used by the invention. 4 is a schematic illustration of the image synthesis of the display system.

### Best Mode for Carrying Out the Invention

Figure 1a show a projector 100 placed on a table 10 and oriented at a display surface 101 so that a projected image 102 is perfectly rectangular. This requires that the optical axis of the projector 100 be perfectly aligned perpendicularly to the plane of the display surface 101, and that there is no rotation about the optical axis.

Figure 1b shows a projector 103 placed obliquely on the table 10 and aimed at the display surface 101. In this case, a projected image 104 is some arbitrary shaped quadrilateral due to the oblique angle between the optical axis and the display surface.

The present invention describes a method and system to correct the distorted image 104 to the required rectangular shape 102 as seen in Figure 1. As a result, this allows a user to casually place a projector on a surface, without being concerned if the table top is perfectly horizontal, and the projectors optical axis is perfect perpendicular to the display surface.

As shown in Figures 3a-3b, when the projector is placed obliquely, or the table is titled, or the floor is tilted, or any combinations of these, the obliqueness can be expressed in terms of the three angles, elevation 301, roll 303, and azimuth 305. Each angle is a measurement between the actual angle of

the optical axis 311 and the ideal angle 312 of the optical axis, i.e., perpendicular to the display surface and no rotation. In the ideal setup, as shown in Figure 1, all the three angles are zero.

In the present invention, the values of these three angles 301-303 are determined automatically using sensors mounted on the projector 200 as shown in Figure 2. Figure 2 shows the projector 200 according to the invention. The projector 200 includes multiple sensors, e.g., tilt sensor 201-202, and a camera 203. The sensors 201-202 can also be accelerometer implemented using 2D-accelerometer boards, for example, the ADXL-202 from Analog Devices, Inc. The camera 203 can be any digital camera with digital out-put signals. The camera 203 acquires an input image of a registration image having a predetermined pattern, e.g., a checkerboard pattern. These are well known.

It should be noted that the angles 301-303 shown in Figure 3 can be sensed by other techniques such as lasers, magnetic sensors, or gyro sensors. With fewer sensors, e.g., one or two, some keystone effects can be compensated. For example, a single sensor can correct for a non-zero elevation angle 301.

The sensors 201-203 are coupled to a processor 210. The processor 210 is conventional in terms of its hardware and operating system software. Application software implements the

method 211 according to the invention. The method 4001 warps images, before they are projected, according to measurements taken by the sensors 201-203. The warping causes the otherwise arbitrary quadrilateral 104 to be projected appear as a rectangle.

The elevation angle 301 and the roll angle 320 are independent of the geometric relationship between the projector 200 and the display surface 101. Hence, these two angles can be sensed or measured using tilt or gravity sensors. For example, the sensor 201 is placed parallel to the optical axis of the projector, and the sensor 202 that measures the roll angle 302 around the optical axis it is placed perpendicular to the optical axis of the projector. The azimuth angle 303 is determined by viewing a projected image with the camera 203.

The azimuth angle 303 is derived from a single planar projective transformation (homography) between pixel locations in the projected image and corresponding pixel locations in an input image acquired by the camera 203 of the projected image, described in greater detail below.

Figure 4 shows the steps of the warping 400 according to the invention. Typically, the computer application 211 generates a rectangular image 400, having corners generally marked A, B, C, and D. The method 400 determines a suitable

quadrilateral 401, which when projected onto the display surface 1091, appears as a correct displayed image 402, i.e., the image is rectangular and axis aligned with the real world sense of what is horizontal and vertical.

The warping 400 scan converts the image 400 into the quadrilateral (warped) image 401 using the homography determined from the sensor measurements. The warping can be performed by texture mapping or image warping such as is available in conventional rendering engines. The homography is defined by the three angles 301-303. The warped image 401 is the input for the obliquely positioned projector 200 according to the invention. The correct displayed image 402 is an axis aligned rectangle that fits inside the quadrilateral 104. In the shown example, the axes are horizontal and vertical directions.

#### Rendering Process Given Three Angles using 3D Graphics

The elevation and roll angles 301-302 are determined directly from the sensor 201-202. The azimuth angle 303 is determined by the following steps. Using the calibrated camera-projector pair, find the location of features in the input image acquired by the camera 203 of the registration image, e.g., corners or lines of the checkerboard pattern. The features are located in 3D in projector coordinate system. The projector coordinate system has a center of projection at the optical center

of the projector, and an optical axis along the positive z-axis of the projector coordinate system.

The equation of a plane passing through at least three features is determined. The normal of this plane is  $N = [N_x, N_y, N_z]$ . A projection in the x-y plane is  $N_{xy} = [N_x, N_y, 0]$ . The dot product of a normalized  $N_{xy}$  and projector optical axis  $[0 \ 0 \ 1]$  is the cosine of the azimuth angle  $= \cos^{-1}(N_{xy} \cdot [0 \ 0 \ 1])$ . After the three angles are determined, there are a number of ways of warping and rendering a correct image. Here, is a preferred method.

The projector illuminates an image with width  $W$  and height  $H$  at a distance  $D$  from the projector. This situation can be represented by a 3D coordinate system with the projector is at the origin and the illuminated rectangle on the display surface 101 is parallel to the x-y plane at  $z = D$ .

The extents of the projected quadrilateral are  $[W_{\text{Left}}, W_{\text{Right}}]$  along x-dimension, and  $[H_{\text{Bottom}}, H_{\text{Top}}]$  along the y-dimension,  $W = |W_{\text{Right}} - W_{\text{Left}}|$  and  $H = |H_{\text{Top}} - H_{\text{Bottom}}|$ . This type of projection cone can be represented by a 3x3 perspective projection matrix  $P$  indicating the internal parameters of the projector that define the focal length and image center.

The three angles elevation, roll, and azimuth correspond

to three 3x3 rotation matrices  $R_e$ ,  $R_r$ ,  $R_a$ . The goal is to render the source image texture mapped on a rectangle of size  $W \times H$ . The rectangle is axis aligned in the x-y plane, and centered at the origin. The image is calculated from a rendering camera, with parameters  $P$  and the transformation defined below. This will give the required warping effect. A point  $[X, Y, 0]$  on the rectangle in x-y plane is mapped to a pixel  $[x, y]$  with the following transformation and projection equation:

$$[x \ y \ 1]^T \approx P * [(R_r * R_e * R_a * [X \ Y \ 0]^T) + [x_s, \ y_s, \ D]^T],$$

where  $x_s = (W_{\text{Left}} + W_{\text{Right}})/2$ , and  $y_s = (H_{\text{Bottom}} + H_{\text{Top}})/2$ .

A second method achieves the same effect by warping the source image with a 3x3 homography matrix  $H$  between the corresponding set of points  $\{m\}$  and  $\{n\}$ .

If

$$[n_x \ n_y \ 1]^T \approx P * [(R_r * R_e * R_a * (([m_x \ -x_s] \ [m_y \ -y_s] \ 0)^T) + [x_s, \ y_s, \ D]^T),$$

then the homography  $H$  is given by

$$[n_x \ n_y \ 1]^T \approx H * [m_x \ m_y \ 0]^T.$$

Four or more pairs of  $\{m = (m_x, m_y)\}$  and  $\{n = (n_x, n_y)\}$  are sufficient to determine the homography matrix  $H$ . A good set of choices for candidate  $\{m\}$  used in homography computation are the corners of the image rectangle  $W \times H$ .

The invention effectively enables casual placement of a projector to generate correct imagery without distortion eliminating expensive electro-mechanical adjustments. The invention makes it possible to install a projector in any orientation e.g. upside down or resting on its side, and detect the parameters of correct imagery by adding sensors along various directions.

This invention is described using specific terms and examples. It is to be understood that various other adaptations and modifications may be made within the spirit and scope of the invention. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the invention.

## CLAIMS

1. A method for correcting keystone in a projector arbitrarily oriented with respect to a display surface, comprising;

measuring an elevation angle, a roll angle, and an azimuth angle of an optical axis of the projector with respect to the display surface;

determining a planar projective transformation matrix from the elevation, roll, and azimuth angles;

warping a source image to be projected by the projector according to the planar projective transformation; and

projecting the warped source image onto the display surface.

2. The method of claim 1 wherein the elevation and roll angles are measured by tilt sensors, and the azimuth angle is a camera coupled to the projector.

3. The method of claim 2, further comprising:  
acquiring an input image of a registration image; and  
determining the azimuth angle from the input image.

4. The method of claim 1 further comprising:  
measuring the elevation angle with a tilt sensor.

5. The method of claim 1 further comprising:  
measuring the roll angle with a tilt sensor.

6. The method of claim 1 further comprising:  
measuring the azimuth angle with a camera-projector  
pair.

7. The method of claim 1 wherein the projector uses a  
laser beam.

8. A system for correcting keystone in a projector  
arbitrarily oriented with respect to a display surface,  
comprising;

a first tilt sensor measuring an elevation angle of an  
optical axis of the projector with respect to the display surface;

a second tilt sensor measuring a roll angle of an optical  
axis of the projector with respect to the display surface;

a camera coupled to the projector measuring an azimuth  
angle of an optical axis of the projector with respect to the  
display surface;

means for determining a planar projective  
transformation matrix from the elevation, roll, and azimuth  
angles; and

means for warping a source image to be projected by the  
projector according to the planar projective transformation and  
projecting the warped source image onto the display surface with

the projector.

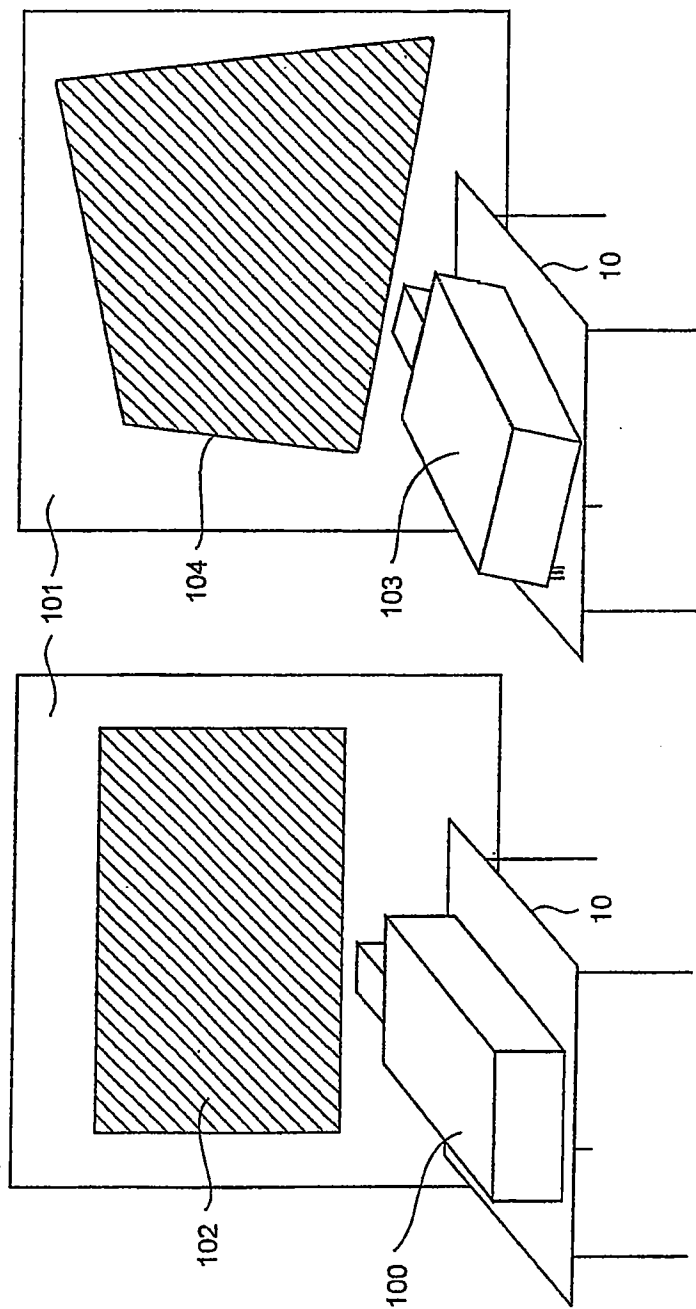


FIG. 1b

FIG. 1a

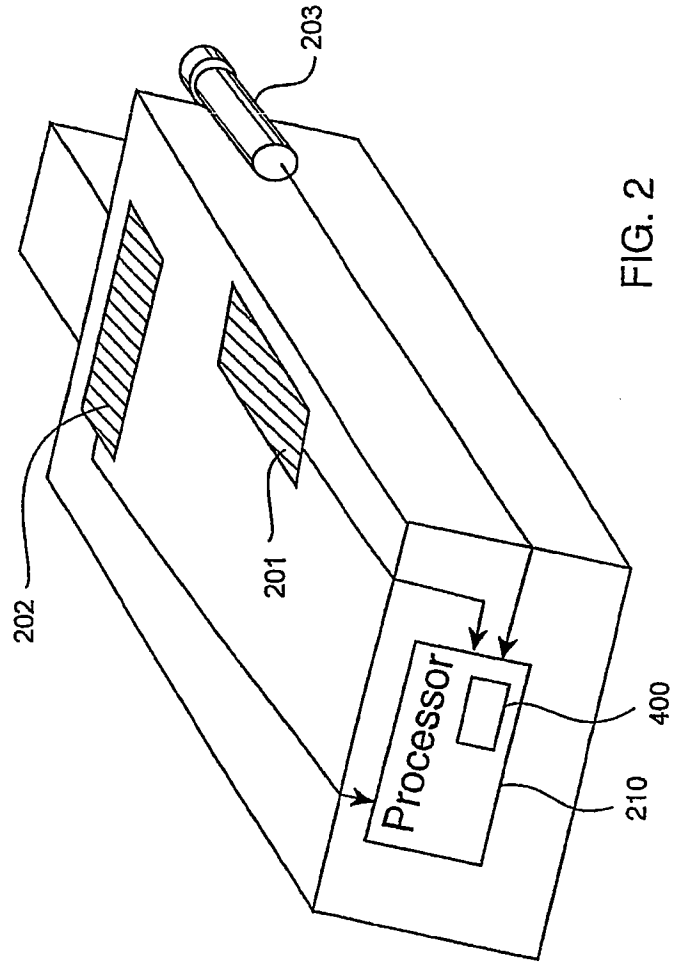


FIG. 2

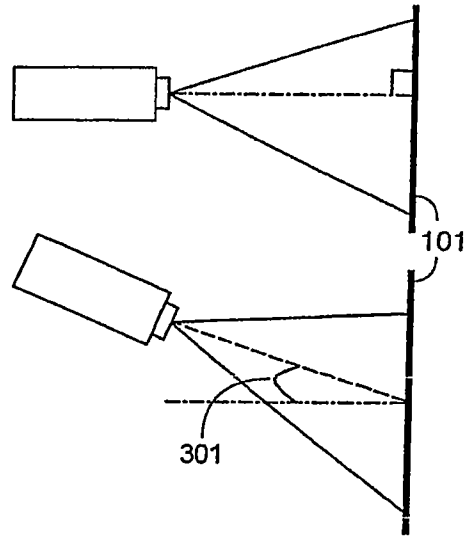


FIG. 3a

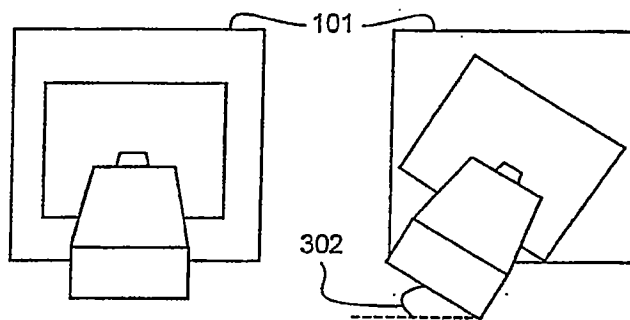


FIG. 3b

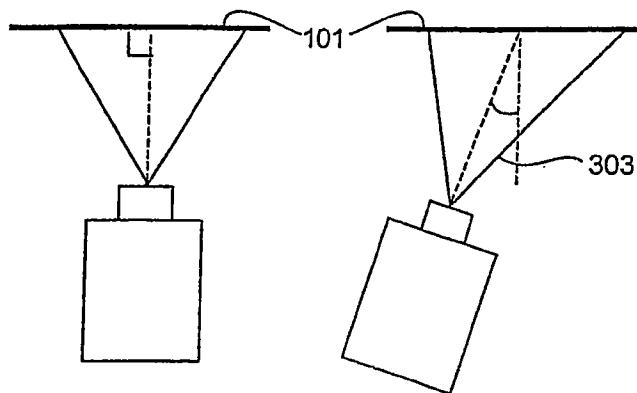
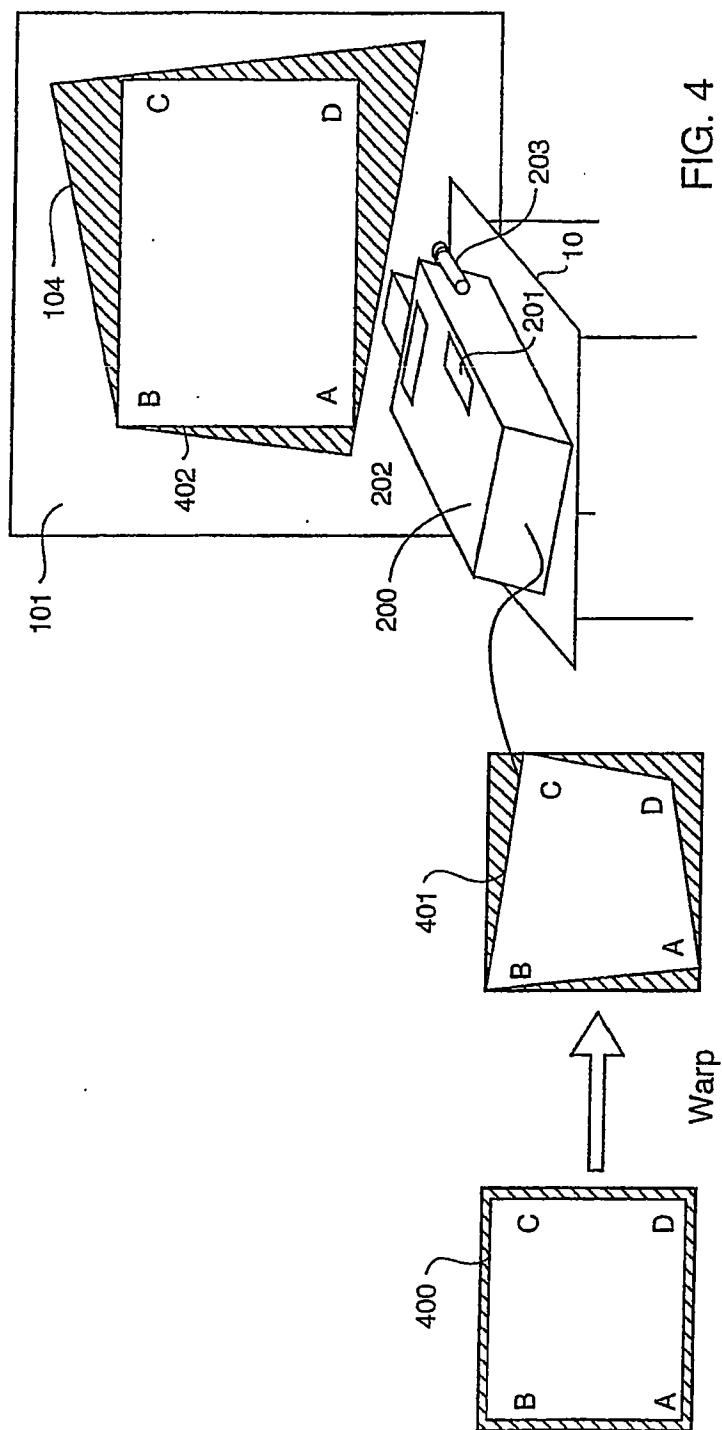


FIG. 3c



## INTERNATIONAL SEARCH REPORT

International Application No

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A. CLASSIFICATION OF SUBJECT MATTER  
 IPC 7 H04N5/74 G03B21/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
 IPC 7 H04N G03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

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|------------|---|-----------------------|
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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## INTERNATIONAL SEARCH REPORT

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## C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages  | Relevant to claim No. |
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Information on patent family members

International Application No

PCT/JP 02/07919

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